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- (57) **ABSTRACT**

An integrated circuit including a Phase Locked Loop (PLL) configured for use with a continuous stream receiver is disclosed. A control voltage line is configured to deliver a control voltage with a capacitive load delivered by a capacitor array to the control voltage based upon an add signal and a subtract signal. A threshold generator generates a high threshold voltage and a low threshold voltage using and including at least one process dependent resistor and at least two temperature and process dependent current sources. The PLL responds during calibration to the control voltage being above the high threshold voltage by asserting the add signal directing the capacitor array to increase the capacitive load on the control voltage line, and to the control voltage being below the low threshold voltage by asserting the subtract signal to decrease the capacitive load.

### Related U.S. Application Data

- 25 Claims, 6 Drawing Sheets**

- (52) **U.S. Cl.**  
USPC ..... **455/260**; 327/156; 375/376

- (58) **Field of Classification Search**  
USPC ..... 455/76, 180.3, 260, 262, 265; 327/156;  
375/376

See application file for complete search history.

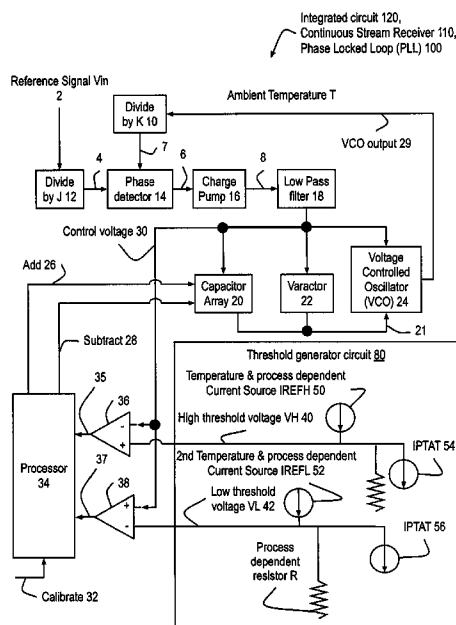


Fig. 1

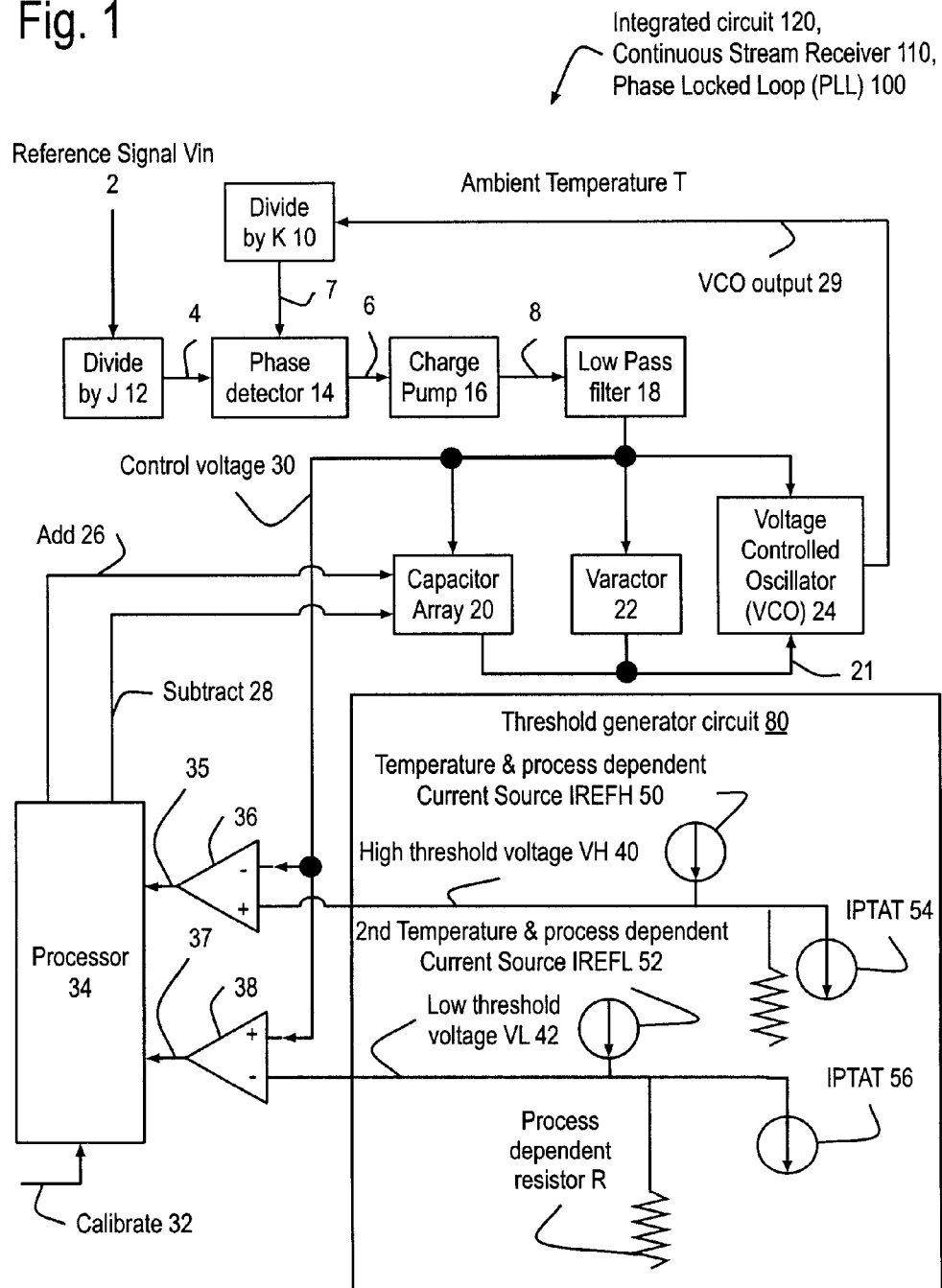


Fig. 2

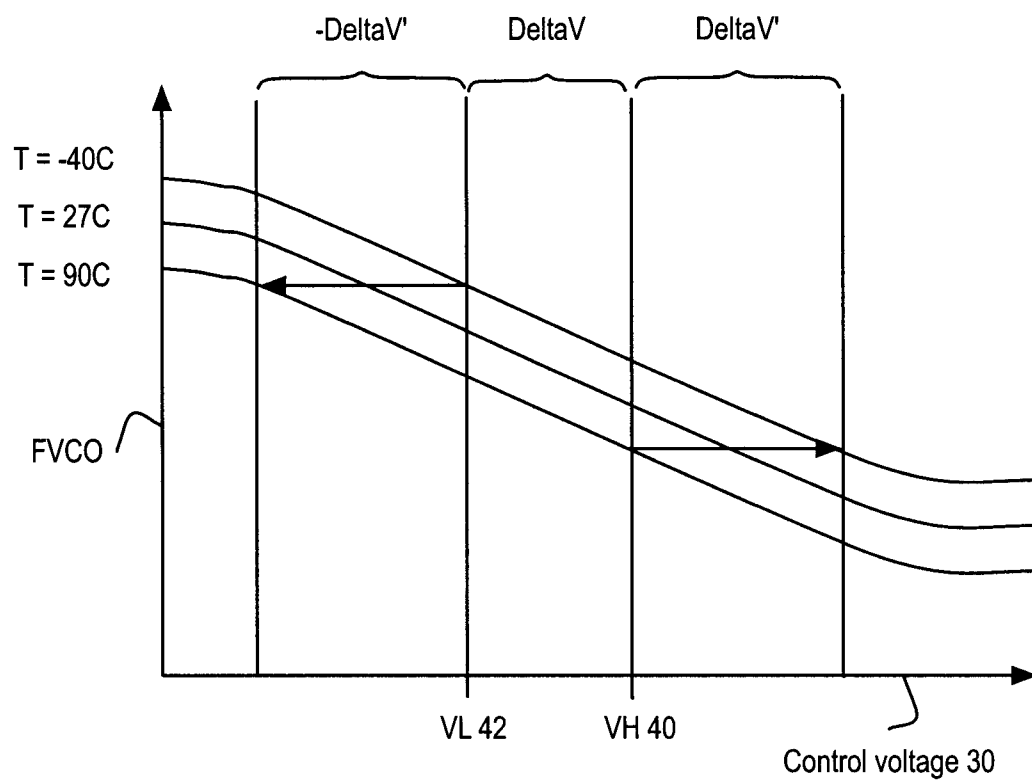


Fig. 3

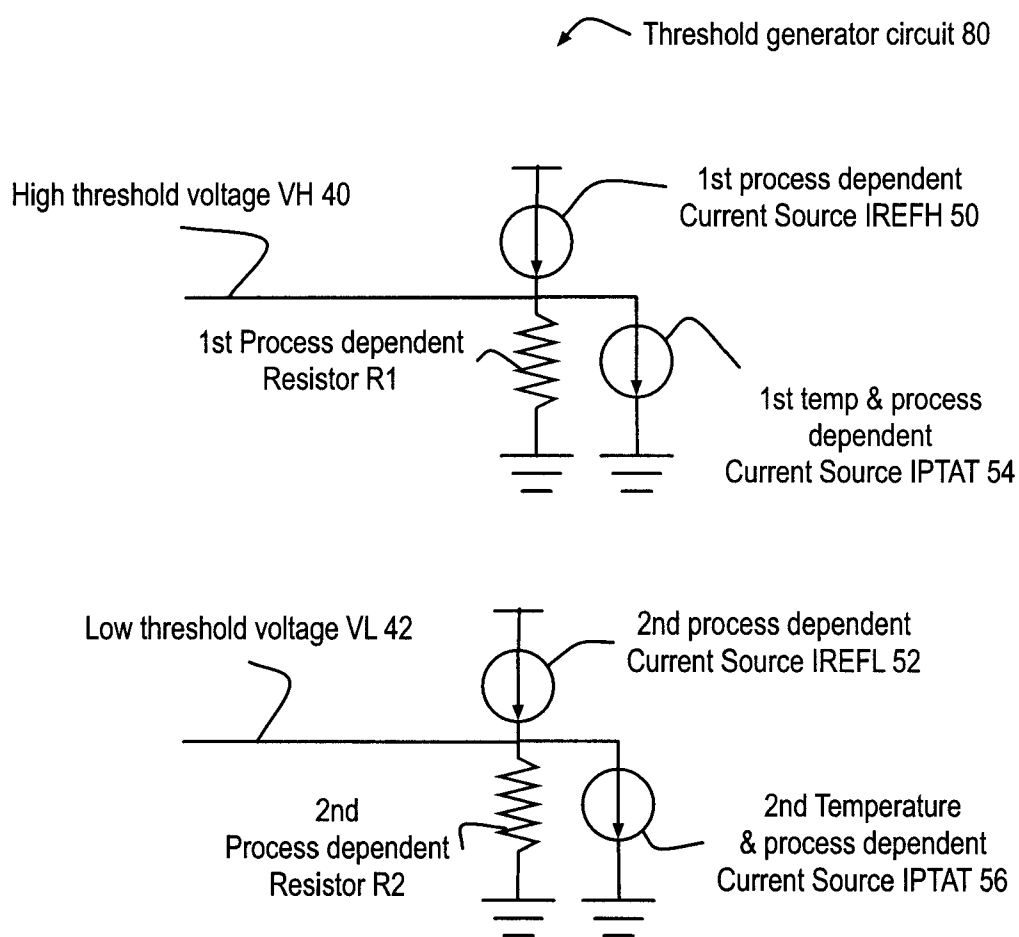


Fig. 4

Threshold generator circuit 80

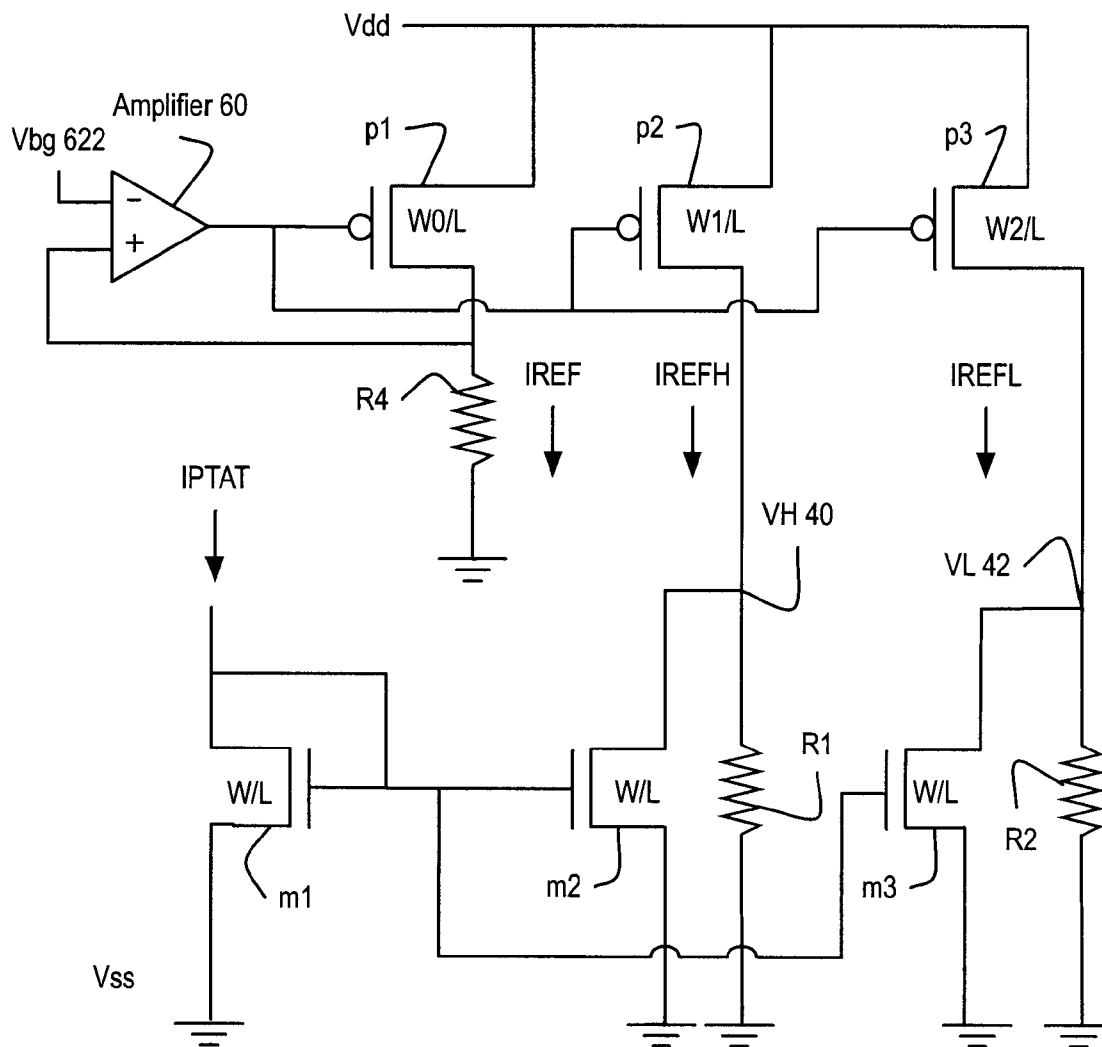


Fig. 5

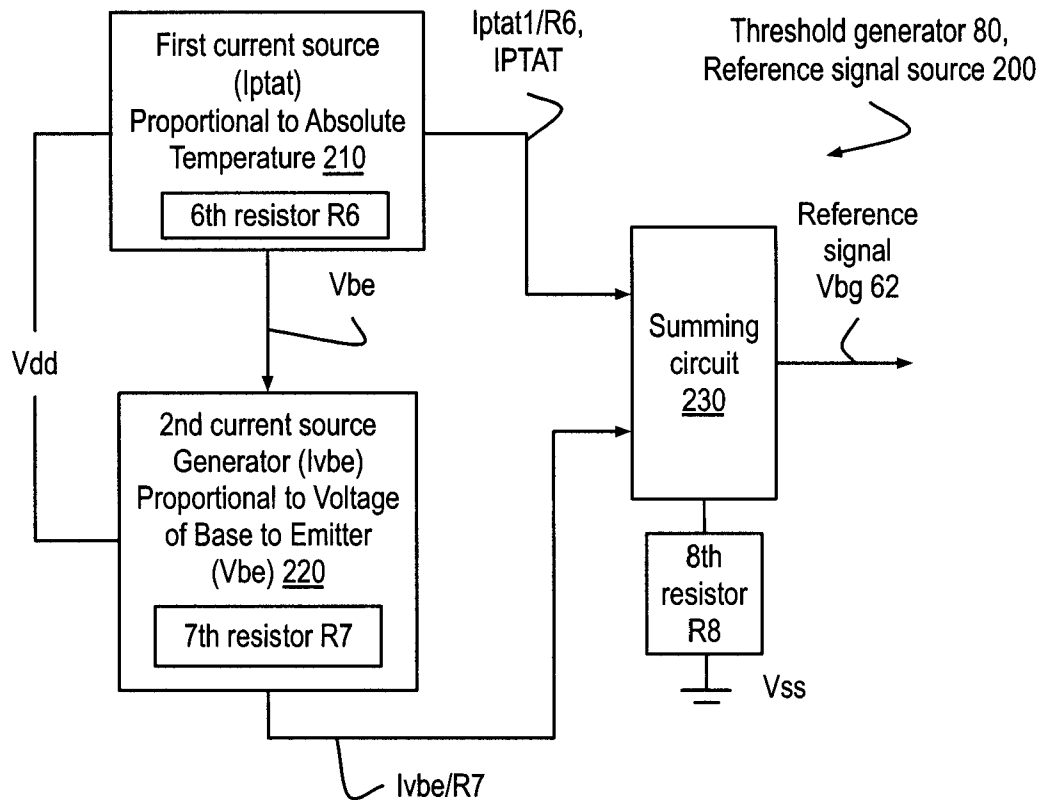
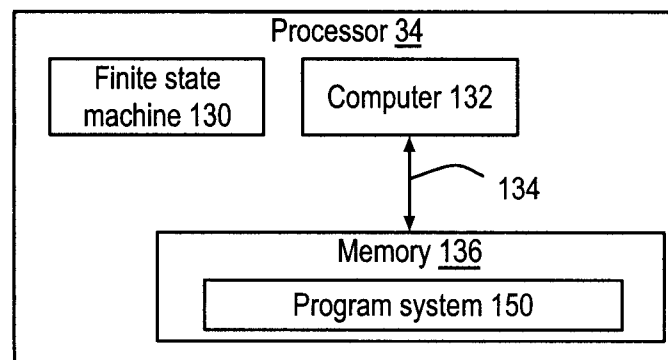


Fig. 6



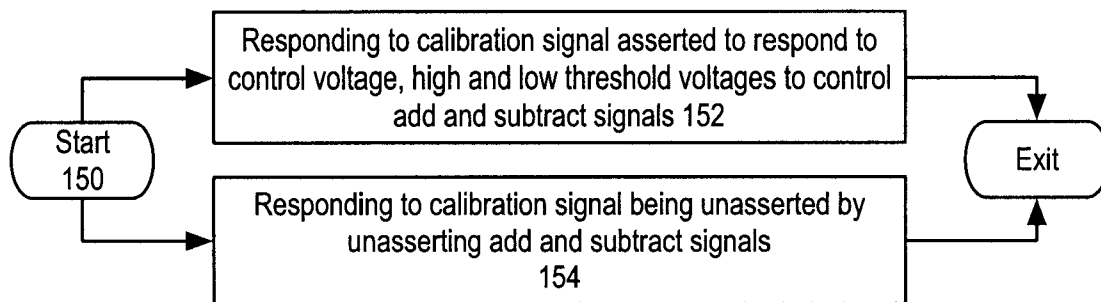


Fig. 7

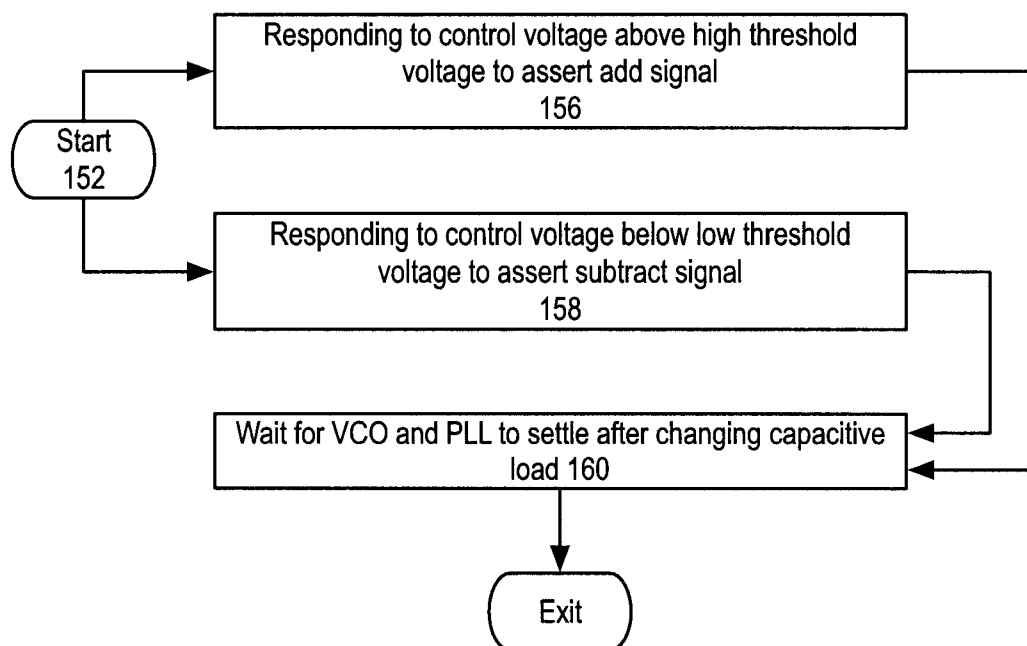


Fig. 8

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# METHOD AND APPARATUS FOR A TEMPERATURE COMPENSATED PHASE LOCKED LOOP SUPPORTING A CONTINUOUS STREAM RECEIVER IN AN INTEGRATED

## RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 12/558,388 filed Sep. 11, 2009.

## TECHNICAL FIELD

This invention relates to temperature compensation in a Voltage Controlled Oscillator (VCO) for use in a Phase Locked Loop (PLL) that supports receivers of a continuous stream such as in a Global Positioning System (GPS) receiver or a mobile television receiver.

## BACKGROUND OF THE INVENTION

Today it is common for many receivers to use a Phase Locked Loop (PLL) driven internally by a Voltage Controller Oscillator (VCO) to generate a frequency and phase synchronized signal that may be used in a variety of signal generation activities such as down conversion, generating an intermediate frequency signal, isolation of a physical channel and/or demodulation of one of these into an analog or digital channel signal. Integrated circuits in the last few years have come to include these receivers in single components at what has often been a major savings in production cost. While these advances are impressive, there are some situations that must be accounted for. Integrated circuit manufacturing processes have some variations, often referred to as process variations that can affect the operation of the VCO. Additionally, the VCO's performance may vary with the ambient temperature within the integrated circuit. The central problem to be addressed here is how to cost effectively calibrate the VCO to take into account process variations and the ambient temperature of the integrated circuit at calibration time.

While it is well known that VCO's and the PLL's they support can be calibrated at the time of manufacturing and test, these calibration processes add to the manufacturing cost of the integrated circuits. Methods and apparatus are further needed that reduce the manufacturing costs while guaranteeing that these components will operate in their favored control voltage range given the ambient temperature and process variations encountered in making and operating the integrated circuit.

## SUMMARY OF THE INVENTION

Embodiments may include an integrated circuit and a Phase Locked Loop (PLL) configured for use with a continuous stream receiver. The PLL may include a control voltage line configured to deliver a control voltage, a capacitor array coupled to the control voltage line and configured to deliver a capacitive load to the control voltage based upon an add signal and a subtract signal, and a threshold generator configured to generate a high threshold voltage and a low threshold voltage using and including at least two process dependent resistors R, at least two process dependent current sources **50** and **52**, and at least two temperature and process dependent current sources **54** and **56**. The PLL responds to a calibration signal being asserted as follows. The PLL responds to the control voltage being above the high threshold voltage by asserting the add signal directing the capacitor

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array to increase the capacitive load on the control voltage line. The PLL responds to the control voltage being below the low threshold voltage by asserting the subtract signal directing the capacitor array to decrease the capacitive load.

The threshold generator may include the first process dependent current source **50** coupled to the high threshold voltage VH **40** and/or a second process dependent current source **52** coupled to the low threshold voltage VL **42**. The threshold generator may include a first temperature and process dependent current source **54** coupled to the high threshold voltage and/or a second temperature and process dependent current source **56** coupled to the low threshold voltage. At least one of the current sources may include or use a current mirror coupled to another current source.

The threshold generator **80** may include a first process dependent resistor R1 coupled to the high threshold voltage and/or a second process dependent resistor R2 coupled to the low threshold voltage. These resistors may each have the same resistance R.

The threshold generator **80** may include at least one instance of a PMOS transistor, an NMOS transistor, a bipolar transistor and a gallium arsenide transistor.

The PLL may further include a processor **34** that may use the low and high voltage thresholds during calibration to change the capacitive load on the control voltage line **30** that may drive the VCO **24** to create a VCO output. Once calibration is completed, the determinations of the control voltage straying above the high or below the low voltage threshold may be ignored until the PLL operations fail, when the processor may again calibrate the PLL.

The integrated circuit **120** may include the continuous stream receiver **110** configured to use the PLL **100**, in particular the receiver may further use the VCO output **29** generated in response to the control voltage presented the capacitive load by the capacitor array and the time-varying capacitance by the varactor **22**. The receiver may include the PLL. The continuous stream receiver may support at least one version of a Global Positioning System (GPS) receiver standard and/or a Mobile TV standard.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an example of embodiments of an integrated circuit including a Phase Locked Loop (PLL) configured for use with a continuous stream receiver with the PLL including a threshold generator **80** configured to generate a high threshold voltage **40** and a low threshold voltage **42** using and including at least one process dependent resistor R and at least two process dependent current sources **50** and **52** and at least two temperature and process dependent current sources **54** and **56**.

FIG. 2 shows a simplified plot of three ambient temperatures T of  $-40$  degrees Celsius (C.) referred to as 'cold',  $27$  degrees C. referred to as 'room' and  $90$  degrees C. referred to as 'hot' showing the FVCO frequency of the VCO output of FIG. 1 vertically against the control voltage range horizontally. The plot shows the location of the window of calibration of the VCO, where the window is between VL **42** and VH **40**, which moves according to the ambient temperature and it's location is optimized such that the VCO operates in it's linear region. If the temperature is hot the calibration window will be on the left side, if it's at room temperature the calibration window is at the middle, while for cold it will reside towards the right side of the figure.

FIG. 3 shows some exemplary details of the threshold generator **80** of FIG. 1 that may include a first process dependent current source **50** coupled to a first temperature and



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process dependent current source **54** to generate the high threshold voltage **VH 40** and/or a second process dependent current source **54** coupled to a second temperature and process dependent current source **56** to generate the low threshold voltage **VL 42**, with each of the threshold voltages coupled to separate process dependent resistors **R1** and **R2**.

FIG. **4** shows an example of some details of the threshold generator circuit, with a reference voltage such as a bandgap voltage **Vbg** being presented as one of two differential inputs to an amplifier and at least one of the current sources for **IPTAT** is implemented with a current mirror.

FIG. **5** shows a simplified block diagram of a reference signal generator that may provide the bandgap voltage reference signal as well as a temperature and process dependent current source of FIG. **4** where this reference signal generator may be coupled to the threshold generator or included in the threshold generator.

FIG. **6** shows a block diagram of the processor **34** of FIG. **1** that may include at least one instance of a finite state machine and/or at least one instance of a computer accessibly coupled to a memory including a program system for instructing the computer to operate at least part of the PLL in terms of calibrating the capacitive load of the capacitor array on the control voltage line.

FIG. **7** shows a flow chart of some details of the program system responding to the calibration signal being asserted or unasserted.

FIG. **8** shows a flow chart of some details of the program system directing the operations of the PLL to respond to the calibration signal being asserted.

#### DETAILED DESCRIPTION

This invention relates to temperature compensation in a Voltage Controlled Oscillator (VCO) for use in a Phase Locked Loop (PLL) that supports receivers of a continuous stream type such as in a Global Positioning System (GPS) receiver or a mobile television receiver. Embodiments may include an integrated circuit and the Phase Locked Loop configured for use with a continuous stream receiver. The PLL may include a control voltage line configured to deliver a control voltage, a capacitor array coupled to the control voltage line and configured to deliver a capacitive load to the control voltage based upon an add signal and a subtract signal, and a threshold generator configured to generate a high threshold voltage and a low threshold voltage using and including two process dependent resistors, two temperature and process dependent current sources, and two process dependent current sources.

Referring to the drawings more particularly by reference numbers, FIG. **1** shows a simplified block diagram of an example of embodiments of the integrated circuit **120** including the PLL **100** configured for use with the continuous stream receiver **110**. The PLL may include the control voltage line configured to deliver the control voltage **30**, the capacitor array **20** coupled to the control voltage **30** and configured to deliver the capacitive load to the control voltage **30** based upon the add signal **26** and the subtract signal **28**, and the threshold generator **80** configured to generate the high threshold voltage **40** and the low threshold voltage **42** using and including two process dependent resistors **R**, two process dependent current sources **50** and **52**, and two temperature and process dependent current sources **54** and **56**. A return path **21** may be implemented to tie together the capacitor array **20**, the varactor **22** and the VCO **24**.

The PLL **100** may respond to a calibration signal **32** being asserted as follows. The PLL responds to the control voltage

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**30** being above the high threshold voltage **40** by asserting the add signal **26** directing the capacitor array **20** to increase the capacitive load on the control voltage line **30**. The PLL responds to the control voltage being below the low threshold voltage **42** by asserting the subtract signal **28** directing the capacitor array **20** to decrease the capacitive load. In an alternative embodiment, the relationship may be reversed such that the response to the control voltage **30** being above the high voltage threshold voltage may be to assert the subtract signal **28** to lower the capacitance of the capacitor array **20** and so on. When the calibration signal is not asserted (referred to hereafter as unasserted), the PLL may respond by unasserting the add signal and the subtract signals, with the capacitive array "remembering" the capacitive load it is to deliver to the control voltage line. The asserting of a signal such as the calibration signal **32**, the add signal **26** and/or the subtract signal **28**, may make it a Boolean value of 1, or a Boolean value of 0 in other alternative uses of the signal. Different signals may assert with different Boolean values.

The threshold generator **80** may include a first process dependent current source **50** coupled to a first temperature and process dependent current source **54** to generate the high threshold voltage **40** and/or a second process dependent current source **52** coupled to a second temperature and process dependent current source **56** to generate the low threshold voltage **42**, with each threshold voltages coupled to process dependent resistors **R1** and **R2**.

The PLL **100** may include a processor **34** that may use the low and high voltage thresholds **40** and **42** during the assertion of the calibration signal **32** to change the capacitive load on the control voltage line **30** that may drive a Voltage Controlled Oscillator (VCO) **24** to create a VCO output **29**. Once calibration is completed, the determinations of the control voltage straying above the high voltage threshold **40** or below the low voltage threshold **42** may be ignored until the PLL operations fail, when the processor may again calibrate the PLL **100**. The PLL **100** may further include a first comparator **36** configured to receive the control voltage **30** and the high threshold voltage **VH 40** to create a first comparator output **35** that may indicate when the control voltage is above the high threshold voltage **VH 40**. The PLL may also include a second comparator **38** configured to receive the control voltage **30** and the low threshold voltage **VL 42** to create a second comparator output **37** that may indicate when the control voltage **30** is below the low threshold voltage **VL 42**. As used herein, one quantity or measurement may be above a second when it is relatively greater than the second. Alternatively, in certain circumstances, the first may be above the second when it is relatively greater than or equal to the second. Also, a first quantity may be below a second whenever the second is relatively above the first.

The VCO **24** may generate a VCO output **29** having a frequency that varies in response to changes in a control voltage **30**. The frequency of the VCO output may determined in part by a capacitance within the VCO **24** as shown, but may also be determined by a combination of inductance and capacitance. In some VCOs, capacitors may be switched in and out of coupling to the control voltage line to cause oscillation at a selected frequency value referred to herein as the FVCO. In other VCOs, a voltage controlled capacitor, that is, a capacitor whose value of capacitance changes in response to an applied voltage, is used to set FVCO. Alternatively, a combination of a voltage controlled capacitor and fixed-value switched capacitors may be used as shown in FIG. **1**.

The PLL **100** may receive a reference signal **Vin 2** presented to a divide by **J** circuit **12** to create a divided input waveform **4**. The VCO output **29** may be presented to a divide

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by K circuit 10 to create a divided VCO output waveform 7. The PLL 100 may include a phase detector 14, a low pass filter 18, and the VCO 24 may be connected in a negative feedback circuit. The phase detector 14 compares the phase of the divided input waveform 4 to the phase of the divided VCO output waveform 7 and outputs a compensation signal 6 proportional to the phase difference between the divided input waveform 4 and the divided VCO output waveform 7. The compensation signal may drive a charge pump 8 to create a pumped compensation signal 8 to the low pass filter 18, which reduces the amplitudes of some high frequency components of the signal to create the control voltage 30. The charge pump 16 may act as a frequency detector in some situations. The control voltage 30 may stimulate the VCO 24 to adjust the FVCO of its VCO output 29. Feedback within the PLL 100 causes the VCO control voltage 30 to change until FVCO is the same as the frequency of the divided input waveform 4.

The PLL 100 is phase locked when the frequency FVCO of the VCO output 29 equals the frequency of the divided input waveform 4. The process of bringing the FVCO to equal the divided input waveform frequency is referred to as "capture", and the maximum frequency separation between the PLL input waveform frequency and the VCO output waveform frequency over which phase lock can be achieved is referred to as the "capture range". The capture range is determined in part by the range of the control voltage 30 supporting linear operation of the VCO 24 and further corresponding to linear operation of the varactor 22. A VCO operating outside its limits of linear operation, for example as a result of a VCO control signal having an amplitude that drives the VCO out of its linear range or because a change in the ambient temperature T changes the capacitance in the VCO, generally causes a PLL to fail in capturing the frequency, that is, the PLL fails to phase lock.

The varactor 22 may be implemented as a diode that may be used as a voltage controlled capacitor, which is sometimes called a varicap. The varactor is operating linearly when a change in control voltage 30 produces a proportional change in the varactor's capacitance. However, for a sufficiently large change in applied voltage, the varactor will not tend to produce that proportional change in its capacitance.

The VCO 24 is operating linearly when a change in the control voltage 30 produces a corresponding proportional change in the frequency FVCO of its VCO output 29. A VCO operating outside its linear operating region may not produce the proportional change in FVCO in response to the change in control voltage. Linear operation of the VCO using the varactor 22 to set FVCO requires that the varactor is also operating linearly.

A change in the ambient temperature T in the VCO 24 can also change FVCO for its VCO output 29. The operating temperature range for the VCO and also for the varactor 22 to operate linearly may be between minus forty degrees and ninety degrees Celsius, for example.

The integrated circuit 120 may include the continuous stream receiver 110 configured to use the PLL 100, in particular the receiver may further use the VCO output 29 generated in response to the control voltage 30 presented the capacitive load by the capacitor array 20 and the time-varying capacitance by a varactor 22. The continuous stream receiver 110 may support at least one version of a Global Positioning System (GPS) receiver standard and/or a Mobile TV standard.

FIG. 2 shows a simplified plot of three ambient temperatures T of -40 degrees Celsius (C.) referred to as 'cold', 27 degrees C. referred to as 'room' and 90 degrees C. referred to as 'hot' showing the FVCO frequency of the VCO output of

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FIG. 1 vertically against the control voltage range horizontally. The plot shows the location of the window of calibration of the VCO, where the window is between VL 42 and VH 40, which moves according to the ambient temperature and its location is optimized such that the VCO operates in its linear region. If the temperature is hot the calibration window will be on the left side, if it's at room temperature the calibration window is at the middle, while for cold it will reside towards the right side of the figure. Note that in some embodiments the linear range may be further modified to incorporate a guard band to account for the aging of the integrated circuit 120.

FIG. 3 shows as example of the threshold generator 80 of FIG. 1 that may include a first temperature and process dependent current source 54 coupled to the high threshold voltage 40 and/or a second temperature and process dependent current source 56 coupled to the low threshold voltage 42. In operation, the first temperature and process dependent current source 54 may contribute to producing the high threshold voltage 40 and/or the second temperature and process dependent current source 56 may contribute to producing the low threshold voltage 42.

The threshold generator 80 may include a first process dependent resistor R1 coupled to the high threshold voltage 40 and/or a second process dependent resistor R2 coupled to the low threshold voltage 42 as shown in FIG. 3.

By way of example, consider the first and second temperature and process dependent current sources 54 and 56 to generate essentially the same current IPTAT at a given ambient temperature T. The process dependent resistors R1 and R2 may each have the same resistance R. The high threshold voltage VH 40 may have approximately the following relationship to its current sources IREFH and IPTAT and the process dependent resistor R1:

$$VH = (IREFH - IPTAT) * R \quad (1)$$

Similarly, for the low threshold voltage VL 42 has the following approximate relationship for its current sources IREFL and IPTAT and the process dependent resistor R2:

$$VL = (IREFL - IPTAT) * R \quad (2)$$

Now define DeltaV = VH - VL and choose VH, VL so that DeltaV' is a change in the high threshold voltage VH that is mirror symmetric from the room temperature of 27 degrees Celsius to either the hot temperature of 90 degrees or the cold temperature of -40 degrees. These definitions and choices are summarized in Table One below:

TABLE ONE

showing the relationship between the ambient temperature T, the high threshold voltage 40, the low threshold voltage 42, the Delta V and the Delta V' of FIG. 2.

Ambient Temperature T	High threshold voltage 40	Low threshold voltage 42
Cold (-40 degrees C.)	VH + DeltaV'	VH - DeltaV + DeltaV'
Room (27 degrees C.)	VH	VH - DeltaV
Hot (90 degrees C.)	VH - DeltaV'	VH - DeltaV - DeltaV'

Subtracting the second equation from the first gives DeltaV = VH - VL with

$$DeltaV = (IREFH - IREFL) * R \quad (3)$$

This operating window between VH and VL moves to higher or lower voltages within the operating temperature range by the following amount:

$$DeltaV' = IPTAT * R \quad (4)$$

Given these formulas, definitions, a specific manufacturing process for the integrated circuit **120**, the desired range of the ambient temperature  $T$ , and the range of the output frequency FVCO for the VCO output **29**, one may derive at least a first order approximation of the threshold generator **80** as shown in FIG. **3** which may be further determined to industrial standards without undue experimentation. In certain embodiments, the above analysis may be incrementally modified to account for a high ambient temperature  $T$  tending to become cooler over time, such as when the integrated circuit **120** is taken from a hot summer day into a cooler office building. Similarly, the above analysis may be incrementally modified to account for a low ambient temperature  $T$  tending to become hotter over time, such as when the integrated circuit **120** is taken from a cold winter day into a heated room.

One or more of the current sources **50**, **52**, **54** or **56** may be a current mirror coupled to one of the other current sources as shown in FIG. **4**.

FIG. **4** shows an example of the threshold generator circuit **80**, with a bandgap voltage  $V_{bg}$  being presented as one of two differential inputs to an amplifier **60**, whose other input receives the feedback of its output. The amplifier **60** output is presented to the gates of the  $p1$ ,  $p2$  and  $p3$  PMOS transistors. The sources of the  $p1$ ,  $p2$  and  $p3$  PMOS transistors are all tied to a first voltage rail labeled as  $V_{dd}$ . The drain of the  $p1$  PMOS transistor is coupled through the  $R4$  resistor to a second voltage rail treated as a ground and referred to as  $V_{ss}$ .

The amplifier **60**, the  $p1$  PMOS transistor and the  $R4$  resistor collectively act as a current source for the IREF current, which has the following approximate relationship with the band gap voltage  $V_{bg}$ :

$$I_{REF} = V_{bg}/R4 \quad (5)$$

The temperature and process dependent current source **54** may be implemented as a current mirror for such a current IPTAT that may be produced somewhere else. Here IPTAT is presented to the drain and gate of the  $m1$  NMOS transistor, whose source is coupled to the second voltage rail or ground  $V_{ss}$ . IPTAT is then the current through the  $m2$  and  $m3$  NMOS transistors, each of which has its source tied to the ground  $V_{ss}$ . In certain embodiments, assume that the  $R1$  and  $R2$  process dependent resistors are both instances of the  $R1$  process resistor. The first process dependent current source **50** includes the  $p2$  PMOS transistor, the  $m2$  NMOS transistor and the first process dependent resistor  $R1$ , which collectively generate IREFH based upon the relationship

$$I_{REFH} = I_{REF} * W1/W0 \quad (6)$$

where the lengths of these transistors are essentially the same and labeled  $L$  while the width of the  $p1$  PMOS transistor is  $W0$ , the width of the  $p2$  PMOS transistor is  $W1$ . The first process dependent current source **50** also generates the high threshold voltage  $VH$  **40** based upon the relationship

$$VH = (I_{REFH} - IPTAT) * R \quad (7)$$

The second process dependent current source **52** includes the  $p3$  PMOS transistor, the  $m3$  NMOS transistor and the second process dependent resistor  $R2$  to collectively create the IREFL current based upon the relationship

$$I_{REFL} = I_{REF} * W2/W0 \quad (8)$$

where the width of the  $p3$  PMOS transistor is  $W2$  and the widths of the  $m1$ ,  $m2$  and  $m3$  NMOS transistors are all  $W$ . This same current source operates to create the low threshold voltage  $VL$  **42** based upon the relationship

$$VL = (I_{REFL} - IPTAT) * R \quad (9)$$

Now the previous circuit analysis for FIG. **3** based upon FIG. **2** may be applied to allow one of skill in the art to create a first order approximation of this circuit, which can then be implemented to industrial standards without undue experimentation.

FIG. **5** shows a simplified block diagram of a reference signal source **200** that may be coupled to the threshold generator **80** or may be included in it in other embodiments. The reference signal source **200** may provide the current dependent and process independent current IPTAT as shown in FIG. **4** as well as the band gap voltage  $V_{bg}$  **62** as a reference signal. The reference signal **62** may result from summing **230** a first temperature dependent current  $I_{ptat1}$  scaled by a sixth resistor  $R6$  from a current source **210** and a current proportional to the voltage of the base to emitter of a bipolar transistor scaled by a seventh resistor  $R7$  from the current source **220**. The summing circuit **230** may use a resistive path to ground through the eighth resistor  $R8$ .

The threshold generator **80** may include at least one instance of a PMOS transistor such as  $p1$  in FIG. **4**, an NMOS transistor such as  $m1$ , a bipolar transistor and/or a gallium arsenide transistor, which have not been shown.

FIG. **6** shows the processor **34** may including at least one instance of a finite state machine **130** and/or at least one instance of a computer **132** accessibly coupled **134** to a computer readable memory **136** and instructed by a program system **150** to operate the processor.

As used herein, any computer **132** includes at least one data processor and at least one instruction processor instructed by a program system **150**, where each of the data processors is instructed by at least one of the instruction processors.

As used herein, a finite state machine **130** receives at least one input, maintains and updates at least one state and generates at least one output based upon the value of at least one of the inputs and/or the value of at least one of the states.

FIGS. **7** and **8** show flowcharts of various details of the program system **150** implementing various operational embodiments of the access point. These flowcharts show some method embodiments, which may include arrows signifying a flow of control, and sometimes data, supporting various implementations. These may include a program operation, or program thread, executing upon the computer **132** or states of a finite state machine **130**. Each of these program steps may at least partly support the operation to be performed. The operation of starting a flowchart refers to entering a subroutine or a macro instruction sequence in the computer or of a possibly initial state or condition of the finite state machine. The operation of termination in a flowchart refers to completion of those operations, which may result in a subroutine return in the computer or possibly return the finite state machine to a previous condition or state. The operation of terminating a flowchart is denoted by a rounded box with the word "Exit" in it.

FIG. **7** shows some details of the program system **150** of FIG. **6** including at least one of the following. Program step **152** supports responding to the calibration signal **32** being asserted to respond to the control voltage **30**, the high threshold voltage **40** and the low threshold voltage **42** to control the add signal **26** and the subtract signal **28**. Program step **154** supports responding to the calibration signal being unasserted to unassert the add signal and the subtract signal.

FIG. **8** shows some details of the program step **152** responding to the calibration signal **32** being asserted. Program step **156** supports responding to the control voltage **30** being above the high threshold voltage  $VH$  **40** to assert the add signal **26**. Program step **158** supports responding to the control voltage **30** being below the low threshold voltage  $VL$  **42**

to assert the subtract signal **28**. Both of these program steps may proceed to program step **160** which supports waiting for the VCO **24** and the PLL **100** to settle after changing the capacitive load in the capacitor array **20**.

Program step **156** may further use the first comparator output **35** to determine when to respond to the control voltage **30** being above the high threshold voltage **VH 40**.

Program step **158** may further use the second comparator output **37** to determine when to respond to the control voltage **30** being below the low threshold voltage **VL 42**.

The preceding embodiments provide examples and are not meant to constrain the scope of the following claims.

What is claimed is:

1. A phase locked loop (PLL) circuit comprising:
  - a voltage controlled oscillator (VCO) configured to generate an output based, at least in part, on a control voltage delivered via a control voltage line;
  - a capacitor array coupled with the VCO via the control voltage line, the capacitor array configured to deliver a capacitive load to said control voltage based on a capacitor control signal;
  - a threshold generator configured to:
    - detect an ambient temperature associated with the PLL circuit, and
    - generate a high threshold voltage and a low threshold voltage based, at least in part, on the ambient temperature; and
  - a comparator processing unit coupled with the capacitor array and the threshold generator, the comparator processing unit configured to:
    - determine whether said control voltage is greater than the high threshold voltage or less than the low threshold voltage, and
    - provide the capacitor control signal to the capacitor array to modify the capacitive load delivered to said control voltage based on determining said control voltage is greater than the high threshold voltage or less than the low threshold voltage.
2. The PLL circuit of claim 1, wherein the comparator processing unit comprises:
  - a first comparator configured to compare said control voltage to the high threshold voltage to determine if said control voltage is greater than the high threshold voltage;
  - a second comparator configured to compare said control voltage to the low threshold voltage to determine if said control voltage is less than the low threshold voltage; and
  - a processor configured to provide the capacitor control signal to the capacitor array to modify the capacitive load delivered to said control voltage in response receiving an output from the first comparator indicating said control voltage is greater than the high threshold voltage or in response to receiving an output from the second comparator indicating said control voltage is less than the low threshold voltage.
3. The PLL circuit of claim 2, wherein the processor is configured to:
  - provide an add capacitor control signal to the capacitor array to increase the capacitive load delivered to said control voltage in response receiving the output from the first comparator indicating the control voltage is greater than the high threshold voltage; and
  - provide a subtract capacitor control signal to the capacitor array to decrease the capacitive load delivered to said control voltage in response receiving the output from the

second comparator indicating the control voltage is less than the low threshold voltage.

4. The PLL circuit of claim 2, wherein, in response to the processor detecting an asserted calibration signal, the processor is configured to provide the capacitor control signal to the capacitor array to modify the capacitive load delivered to said control voltage in response receiving an output from the first comparator indicating the control voltage is greater than the high threshold voltage or in response to receiving an output from the second comparator indicating the control voltage is less than the low threshold voltage.

5. The PLL circuit of claim 1, wherein the comparator processing unit is configured to adjust said control voltage delivered to the VCO using the capacitor control signal provided to the capacitor array to modify the capacitive load delivered to said control voltage.

6. The PLL circuit of claim 1, wherein the threshold generator comprises at least one process dependent resistor and at least two process dependent current sources operable to generate the high threshold voltage and the low threshold voltage based on the ambient temperature.

7. The PLL circuit of claim 6, wherein the threshold generator comprises:

- a first of the process dependent current sources coupled to a high threshold voltage line; and
- a second of the process dependent current sources coupled to a low threshold voltage line.

8. The PLL circuit of claim 7, wherein the threshold generator further comprises:

- a first temperature and process dependent current source coupled to the high threshold voltage line, the first temperature and process dependent current source and the first process dependent current source operable to generate the high threshold voltage based on the ambient temperature; and
- a second temperature and process dependent current source coupled to the low threshold voltage line, the second temperature and process dependent current source and the second process dependent current source operable to generate the low threshold voltage based on the ambient temperature.

9. The PLL circuit of claim 8, wherein one of the temperature and process dependent current sources is implemented as a current mirror coupled to the other of the temperature and process dependent current sources.

10. The PLL circuit of claim 8, wherein the threshold generator comprises at least one of:

- a first process dependent resistor coupled to the high threshold voltage line; and
- a second process dependent resistor coupled to the low threshold voltage line.

11. The PLL circuit of claim 1, further comprising:

- a phase detector configured to:
  - receive a reference signal and a divided version of the output of the VCO, and
  - compare a phase of the reference signal to a phase of the divided version of the output of the VCO, and
  - generate a compensation signal proportional to a phase difference between the phase of the reference signal and the phase of the divided version of the output of the VCO; and
- a charge pump coupled to the phase detector, the charge pump configured to generate said control voltage based on the compensation signal.

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12. The PLL circuit of claim 11, further comprising a low pass filter coupled between the charge pump and the VCO, the low pass filter operable to filter high frequency components of said control voltage.

13. The PLL circuit of claim 11, further comprising a varactor coupled to the control voltage line, wherein said control voltage delivered by the control voltage line is modified based on the capacitive load associated with the capacitor array and a capacitance associated with the varactor.

14. The PLL circuit of claim 1, wherein the PLL circuit is part of an integrated circuit of a communication device.

15. A method for implementing a phase locked loop (PLL), the method comprising:

generating, at a voltage controlled oscillator (VCO) of the PLL, a PLL output based, at least in part, on a control voltage delivered to the VCO via a control voltage line; detecting an ambient temperature associated with the PLL; generating a high threshold voltage and a low threshold voltage based, at least in part, on the ambient temperature;

determining whether said control voltage is greater than the high threshold voltage or less than the low threshold voltage; and

modifying said control voltage delivered to the VCO by modifying a capacitive load delivered to said control voltage in response to determining said control voltage is greater than the high threshold voltage or less than the low threshold voltage.

16. The method of claim 15, wherein said modifying the capacitive load delivered to said control voltage in response to determining said control voltage is greater than the high threshold voltage or less than the low threshold voltage comprises providing a capacitor control signal to a capacitor array coupled with the VCO via the control voltage line to modify the capacitive load delivered to said control voltage.

17. The method of claim 15, further comprising:

comparing said control voltage to the high threshold voltage to determine if the control voltage is greater than the high threshold voltage;

comparing said control voltage to the low threshold voltage to determine if the control voltage is less than the low threshold voltage; and

providing a capacitor control signal to a capacitor array coupled with the VCO via the control voltage line to modify the capacitive load delivered to said control voltage in response to determining said control voltage is greater than the high threshold voltage or in response to determining said control voltage is less than the low threshold voltage.

18. The method of claim 17, further comprising:

providing an add capacitor control signal to the capacitor array to increase the capacitive load delivered to said control voltage in response to determining said control voltage is greater than the high threshold voltage; and

providing a subtract capacitor control signal to the capacitor array to decrease the capacitive load delivered to said control voltage in response to determining said control voltage is less than the low threshold voltage.

19. An apparatus for implementing a phase locked loop (PLL), the apparatus comprising:

a voltage controlled oscillator (VCO) configured to generate an output based, at least in part, on a control voltage delivered via a control voltage line;

a capacitor array coupled with the VCO via the control voltage line, the capacitor array configured to deliver a capacitive load to said control voltage based on a capacitor control signal;

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a threshold generator configured to:

detect an ambient temperature associated with the apparatus, and

generate a high threshold voltage and a low threshold voltage based, at least in part, on the ambient temperature; and

a comparator processing unit coupled with the capacitor array and the threshold generator, the comparator processing unit configured to:

determine whether said control voltage is greater than the high threshold voltage or less than the low threshold voltage, and

provide the capacitor control signal to the capacitor array to modify the capacitive load delivered to said control voltage based on determining said control voltage is greater than the high threshold voltage or less than the low threshold voltage.

20. The apparatus of claim 19, wherein the comparator processing unit comprises:

a first comparator configured to compare the control voltage to the high threshold voltage to determine if the control voltage is greater than the high threshold voltage;

a second comparator configured to compare the control voltage to the low threshold voltage to determine if the control voltage is less than the low threshold voltage; and

a processor configured to provide the capacitor control signal to the capacitor array to modify the capacitive load delivered to said control voltage in response receiving an output from the first comparator indicating the control voltage is greater than the high threshold voltage or in response to receiving an output from the second comparator indicating the control voltage is less than the low threshold voltage.

21. The apparatus of claim 20, wherein the processor is configured to:

provide an add capacitor control signal to the capacitor array to increase the capacitive load delivered to said control voltage in response receiving the output from the first comparator indicating the control voltage is greater than the high threshold voltage; and

provide a subtract capacitor control signal to the capacitor array to decrease the capacitive load delivered to said control voltage in response receiving the output from the second comparator indicating the control voltage is less than the low threshold voltage.

22. The apparatus of claim 20, wherein, in response to the processor detecting an asserted calibration signal, the processor is configured to provide the capacitor control signal to the capacitor array to modify the capacitive load delivered to said control voltage in response receiving an output from the first comparator indicating the control voltage is greater than the high threshold voltage or in response to receiving an output from the second comparator indicating the control voltage is less than the low threshold voltage.

23. The apparatus of claim 19, wherein the threshold generator comprises at least one process dependent resistor and at least two process dependent current sources operable to generate the high threshold voltage and the low threshold voltage based on the ambient temperature.

24. The apparatus of claim 19, wherein the threshold generator comprises:

a first process dependent current source and a first temperature and process dependent current source coupled to a high threshold voltage line, the first temperature and process dependent current source and the first process

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dependent current source operable to generate the high threshold voltage based on the ambient temperature; and a second process dependent current source and a second temperature and process dependent current source coupled to a low threshold voltage line, the second temperature and process dependent current source and the second process dependent current source operable to generate the low threshold voltage based on the ambient temperature.

**25.** The apparatus of claim **24**, wherein the threshold generator comprises at least one of:

- a first process dependent resistor coupled to the high threshold voltage line; and
- a second process dependent resistor coupled to the low threshold voltage line.

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